# Design and Implementation of a digital Infrastructure for autonomous Open-Die Forging

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## 1. Introduction

Open die forging, one of the oldest metal forming technologies, remains crucial for manufacturing large components such as generator shafts and crankshafts for ship engines. Although it is mainly applied to single pieces or small production batches, the process still heavily relies on manual labour and the expertise of skilled operators. Traditional automation is impractical due to the high variability and low production volumes, which results in long manufacturing times, frequent adjustments to production plans, and challenges in maintaining consistent quality. In recent decades, there have been some attempts to automate the process using industrial robots, showcasing promising potential for innovation [1].

The process typically involves multiple reheating stages and extended production cycles, which can last days or even weeks. The quality of industrial open die forging is still highly dependent on the operator experience. Retirement of experienced staff and shift work, which is a common industrial working method, introduces variability into the complex production process. These factors make it particularly difficult to achieve consistent process stability, reproducibility, and quality - requirements that are crucial in modern manufacturing, especially with advanced materials technologies.

To address these challenges, a novel concept for autonomous forging has been developed and tested at the Institute of Metal Forming at the Technical University of Freiberg. This system integrates traditional components, such as a furnace and a forging press, with modern technologies. An industrial robot is responsible for handling workpieces, while a custom-designed 3D scanning system captures geometric data to create a digital twin of the workpiece. Thermal imaging cameras provide monitoring of the temperature profile.

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A forging robot cell was developed to meet the basic hardware requirements for autonomous forging. The main challenge in this system was the design of a digital infrastructure to facilitate effective communication between components. In addition, modular process control software was implemented to seamlessly coordinate and operate these components, thereby replacing the role of a human operator.

The robot cell operates as a distributed system, with multiple nodes connected via a local area network (LAN). Key hardware components include a main computer as the human-machine interface, the KUKA Robot Control 2 system for controlling the manipulator, and a position sensor integrated as a web server. The press control system and three blue light line laser scanners are also configured as web servers. Three thermal imaging cameras measure temperatures between 450°C and 1800°C, with the data being accessible via USB interfaces. This combination establishes the foundation for precise, efficient, and autonomous forging operations.

The software architecture follows a modular design to ensure maintainability, facilitate error diagnostics, and enable the replacement or enhancement of individual subsystems. This flexibility is essential for adapting to different manufacturing plants with specific requirements or integrating new technologies in the future. Within the modular software architecture, multiple nodes are implemented according to the logical steps of the forging process. The basic tasks are: workpiece positioning, measuring, heating, deformation, and process planning.

To integrate the KUKA robot as a manipulator into the software architecture and make it accessible for custom process control, a third-party software called RoboDK is used. This software enables offline programming of industrial robots for path planning and process planning. Compared to conventional offline programming software, which only allows the export of programs via a postprocessor, RoboDK provides a software interface for online interaction with the robot. An additional software component was installed on the KUKA robot control system, which works as a web server and enables the exchange of system variables between the robot and the RoboDK client. This software also provides a programming interface for easy integration into custom projects, such as the forging cell. In the current automation setup, a digital twin of the forging cell is created within RoboDK, and transportation paths and programs between each component are set up and tested within this software. Due to the API and the connection to the robot control system, these transportation programs or custom motions, such as linear or joint movements, can also be executed directly from custom software.

The geometry and temperature measurement are achieved through a custom scanning system consisting of three blue light laser scanners and three thermal imaging cameras. Each sensor type is mounted in a vertical plane to measure a part of the crosssection of the workpiece, resulting in a two-dimensional dataset. To generate a three-dimensional digital twin of the workpiece, multiple cross-sectional scans along the longitudinal axis of the workpiece are taken. The scanning system is mounted on a linear actuator, which provides a measurement range of 700 mm. An additional position sensor was added to determine the current position of the scanning system and link it with the geometry and temperature data. This position monitoring is also implemented as a web server, which can be accessed by each sensor individually. The raw geometry and temperature data of the workpiece are stored on the main computer for access by the process planning tool and other use cases.

The process planning itself is designed as an independent tool that uses the geometry and temperature data to calculate a pass sequence. The output includes instructions for positioning the workpiece between the dies of the forging press or in the furnace (rotation and translation), small correction movements to compensate for any tilted gripping of the workpiece, and instructions for the press movement (dimensions). This pass sequence planning can easily be exchanged with custom pass sequence calculation algorithms, depending on the applications, production conditions or goals [2].

In the automation concept at the IMF, the forging press does not provide a native interface for external control, and enhancing it is not straightforward. Therefore, an electromechanical device was created to interact with the human-machine interface of the forging press. This device is also designed as a web server and can provide the current position of the press or based on an instruction, the press is set to a defined gap between the dies. This device enables only displacement-controlled use of the press.

To minimize dependencies between the software modules, a Core-module has been implemented to coordinate the interaction of all software components and subsystems. This approach simplifies the process of exchanging or extending the robot cell or individual subsystems, ensuring that no other subsystems are directly impacted. In the case of a change, only the Core-module needs to be updated to accommodate the new setup, thus maintaining system flexibility and reducing the need for widespread modifications. The overall software architecture, as depicted in Figure 1, illustrates the structure and interaction of the various components within the system.

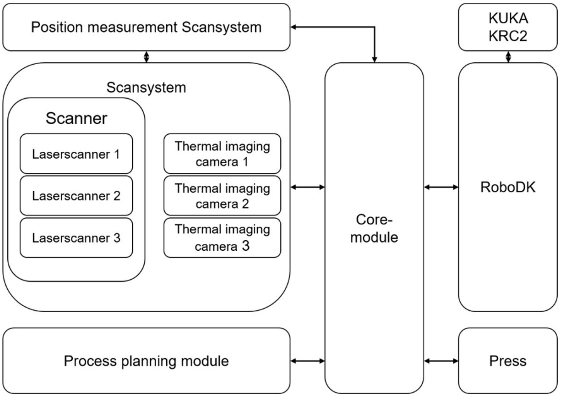


**Figure 1.** Software architecture of the autonomous forging concept

This approach offers a promising platform for implementing customized open die forging process controls, thereby enhancing flexibility in production. By integrating advanced technologies, it aims to improve process control, stability, and quality while addressing challenges such as workforce shortages and the increasing demands of modern material concepts. However, it is important to note that the system is still in the early stages of development. Initial trials show promising results, but further adjustments and testing are required to fully realize its potential. As development continues, the system will be refined to meet the specific needs of modern manufacturing and achieve sustainable improvements in forging operations, particularly in the context of advanced material technologies.

## References


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